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MASTER'S THESIS

JOINT ADMISSION AND ASSOCIATION IN VEHICULAR NETWORKS

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ABSTRACT

To support vehicle to everything (V2X) communication which is an integral part of intelligent transportation systems (ITS), fifth generation (5G) communication systems will need to employ diverse range of technologies, which will ultimately lead to automated driving, improved traffic safety, improved traffic efficiency and infotainment. V2X is considered as one of the most challenging applications of 5G, because it requires ultra reliable and low latency communication (URLLC) for safety critical applications and high data rates in many scenarios under mobility.

Vehicles which can communicate with a base station or road side unit (RSU) are primary vehicles, which can act as relays to secondary vehicles which are out of coverage from the network. Therefore vehicle to infrastructure (V2I) and vehicle to vehicle (V2V) communication are employed to provide coverage for out of coverage vehicles. In this study joint problem of admission control for primary vehicles and user association for secondary vehicles in a singe cell downlink vehicular network is considered. The objective is to maximize the number of admitted primary vehicles, while associating all secondary vehicles. We consider the underlying communication system is based on millimeter wave communication at 60 GHz and we cast the optimization problem as an ℓ_0 minimization problem. This problem is known to be combinatorial and NP-hard. Hence, we propose a sub optimal, two stage algorithm to solve it.

We compare the performance of proposed algorithm against the exhaustive search algorithm. From simulation results it can be observed, although the proposed algorithm is a sub optimal algorithm it gives optimal performance with improved efficiency. Hence, the proposed algorithm is able to determine the optimal association for vehicles which are out of coverage and optimal admission for vehicles which are in coverage.

Keywords: V2X communication, Admission control, User association, Vehicular networks, ℓ_0 minimization, Convex optimization, Millimeter Wave communication

TABLE OF CONTENTS

FOREWORD

This thesis is focused on joint admission and association in vehicular networks. This work was conducted as a part of the High5 and MOSSAF projects at the Center for Wireless Communications (CWC) of University of Oulu, Finland.

I express my deep gratitude to my supervisor and mentor Prof. Nandana Rajatheva for his immense support and guidance throughout my period of masters studies. I express my sincere gratitude to Dr. Shashika Manosha for his valuable support, guidance and encouragement during my master thesis. Also I would like to thank Dr. Vijitha R. Herath from University of Peradeniya for his support and cooperation.

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Finally, I thank my family for their love, kindness and support throughout my journey.

Oulu, 30th July, 2019

Akila Ekanayake

LIST OF ABBREVIATIONS AND SYMBOLS

Acronyms

3GPP	3rd Generation Partnership Project
4G	fourth generation
5G	fifth generation
ADS	automated driving systems
AP	access point
AR	augmented reality
BSM	basic safety message
CP	cyclic prefix
CSMA	carrier sense multiple access
C-V2X	cellular vehicle to everything
DFT	discrete Fourier transform
DMRS	demodulation reference signal
DSRC	dedicated short range communication
eMBB	enhanced mobile broadband
EPS	evolved packet switching
ETSI	European telecommunications standards institute
FDM	frequency division multiplexing
ICT	information and communications technology
IEEE	Institute of Electric and Electronics Engineers
IoT	internet of things
ITS	intelligent transportation systems
LOS	line of sight
MAC	medium access control
MIMO	multiple input multiple output
mMTC	massive machine-type communication
NHTSA	National Highway Traffic Safety Administration
NLOS	non line of sight
NR	new radio
OFDM	orthogonal frequency division multiplexing
PER	packet error rate
PSSCH	physical sidelink shared channels
QAM	quadrature amplitude modulation
QPSK	quadrature phase shift keying
RAT	radio access technology
RB	resource block
RSU	road side unit
SCI	sidelink control information
SINR	signal to interference plus noise ratio
SPS	semi persistent scheduling
TB	transport block
TDM	time division multiplexing
UE	user equipment
URLLC	ultra reliable and low latency communication

V2I	vehicle to infrastructure
V2N	vehicle to network
V2P	vehicle to pedestrian
V2V	vehicle to vehicle
V2X	Vehicle to everything
VR	virtual reality

Symbols

Γ	signal to interference plus noise ratio
$\mathcal{V}$	set of vehicles
$\mathcal{S}$	set of secondary vehicles
$\mathcal{P}$	set of primary vehicles
θ	alignment error
φ	half power beam width
a_{bi}	auxiliary variable
b	base station
d_{ij}	distance between node i and j
$\mathbf{e}$	admission control vector
L_{ij}	link between node i and j
g^c	channel gain
g^r	receiver gain
g^t	transmitter gain
z	side lobe power
N_0	Gaussian background noise power density
X^s	association matrix

Operators

Σ	Summation operation

1 INTRODUCTION

This chapter initiates the thesis by describing the background and motivation about 5G and vehicular communication.

1.1 Background and Motivation

In every industry a digital disruption is happening which is revolutionizing current technologies. In communication systems fifth generation (5G) evolution is creating new use cases focusing on boosting efficiency of lifestyles. Novel opportunities have opened up for traditional telecommunication operators and other industries with the dawn of 5G. Based on distributed cloud services and programmable networks at the edge, new business models are being created.

Collaboration between humans and industries are increasing in the modern world as a result of ability and willingness to share information. New cross industrial developments have created the necessity to evolve current wireless networks in to 5G networks. In comparison to previous generations such as fourth generation (4G), the objectives of 5G development are to expand the broadband capability of mobile networks and to provide specific capabilities for consumer, industries and society at large. This will pave the way for unleashing the potential of the internet of things (IoT) [1].

In the context of 5G communication there are three main classes of use cases that are being discussed. They are enhanced mobile broadband (eMBB), massive machine type communication (mMTC) and ultra reliable and low latency communication (URLLC).

- eMBB corresponds to an evolution of the current mobile broadband services, enabling higher data volumes and further enhanced user experience, for example, by supporting even higher data rates for the end user. It is expected that eMBB will enable stable connections with very high peak data rates and moderate rates for cell edge users. eMBB is considered as an extension of broadband service in 4G. It is characterized by large payloads and by a device activation pattern that remains stable over an extended time interval. The objective of the eMBB service is to maximize the data rate, while guaranteeing a moderate reliability and with packet error rate (PER) on the order of 10^{-3} [2].

- mMTC corresponds to use cases where massive number of devices are used. Massive number of IOT devices will be activated periodically and they transmit small payloads. Very low device cost and very low device energy consumption are the key requirements which allows for long device battery life of up to at least several years. Since each device is expected to transmit and receive small amount of data, support for high data rates is of less importance. In a 5G network large number of mMTC devices will be connected, but at a given time only a random subset of them becomes active and attempt to send their data. It is difficult to allocate priori resources to individual mMTC devices, due to the high number of devices. Therefore, resources should be shared through random access. Maximizing the arrival rate that can be supported in a given radio resource is the objective of mMTC. The targeted PER of an individual mMTC transmission is typically low, e.g., on the order of 10^{-1} [2].

- URLLC services are required to have very low latency and extremely high reliability. Examples for URLLC services are autonomous driving and factory automation. URLLC transmissions are intermittent. In order to support intermittent URLLC transmissions combination of scheduling and random access is used. To guarantee a certain amount of predictability scheduling is used and random access is used to avoid resources being idle. URLLC transmission should be localized in time, due to the low latency requirements. Expected PER is lower than 10^{-5} and rates of a URLLC transmission is relatively low to eMBB and mMTC [2].

Classification of 5G use cases into above three categories is not a natural classification for all use cases, but it simplifies the definition of requirements for the technology specifications. As an example there can be cases which will not belong to any of the above three classes, but it will be a combination of all three use case groups. In Figure 1.1 different use cases of 5G and above mentioned use case classes they belong are illustrated.

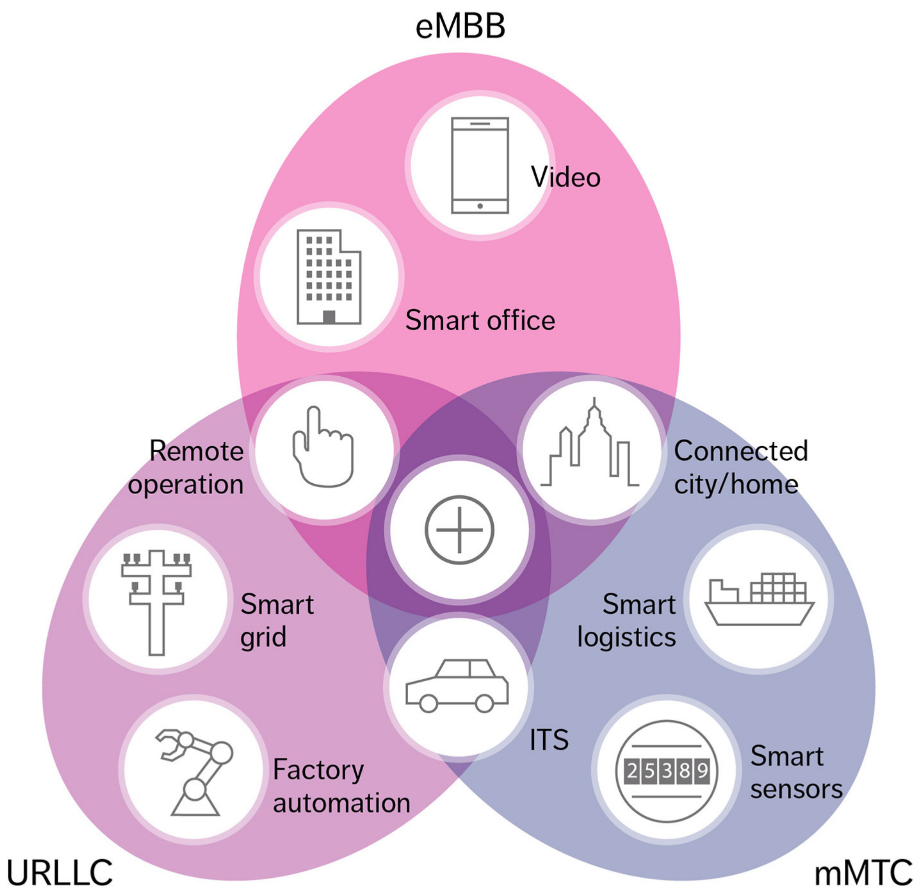

Figure 1.1. 5G use cases [1].

Intelligent transportation systems (ITS), is an umbrella term referring to transportation networks and systems that consists of information and communications technology (ICT), with vehicles and transport infrastructure to improve safety, mobility and environmental sustainability. Wireless connectivity plays a vital role in delivering these services of ITS.

Personal mobility and vehicular transportation systems are undergoing a digital disruption in the modern world. New social and market trends are the reason behind this disruption. According to [3] these main social trends are

- New wave of urbanization creating pressure on the existing transportation infrastructure
- Stringent emission and energy regulations
- High demand on transportation and delivery services to become more reliable and dynamic

Key market trends which affect the disruption are identified as

- Development of automated driving
- New modes of vehicle use and ownership
- Live and open data availability, including crowd sourcing and open platforms, which enables more efficient use of transportation resources.

The technical committee Intelligent Transport Systems (ITS) has been created within European Telecommunications Standards Institute (ETSI) to develop standards and test specifications. Figure 1.2 illustrates communication technologies and services for ITS.

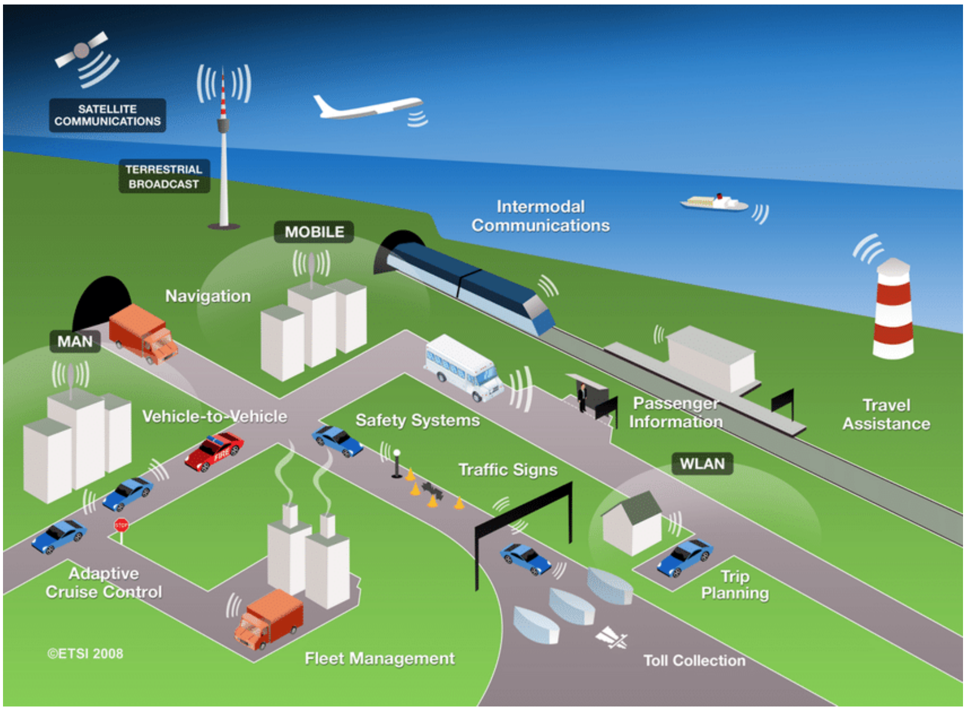

Figure 1.2. Communication technologies and services for ITS [4].

These trends are creating a shift towards more intelligent transport infrastructure in the future.

1.2 Thesis Outline

The remaining of this thesis is organized as follows:

- Chapter 2: Consists of the summary of literature survey related to the research.
- Chapter 3: This chapter provides the details of the work carried out, where the general system model is described, how problem is formulated and the proposed algorithm is derived.
- Chapter 4: Simulation results for different scenarios are considered and for the proposed algorithm and compared with a base line algorithm.
- Chapter 5: This chapter consists of a conclusion section which provides a summary to the thesis work and presents ideas for future work.
- Chapter 6: This chapter provides recommendations for future work.

2 LITERATURE SURVEY

2.1 V2X Communication

Vehicle to everything (V2X) is the umbrella term for the vehicle related communication systems. Third generation partnership project (3GPP) has defined four types of V2X communication based on the elements associated in the communication. They are vehicle to vehicle (V2V), vehicle to pedestrian (V2P), vehicle to infrastructure (V2I) and vehicle to network (V2N) communication.

V2X communication is the key integral component of intelligent transportation systems (ITS), which involves wireless connectivity between the vehicle and its surrounding environment. Vehicles are becoming more intelligent and less reliant on human drivers. Hence, communication happening in V2X is dynamic and involves many systems. ITS consist of a broader range of communication systems, involving overland vehicles and other vehicular transportation systems such as railway, aviation and maritime transportation [5]. In this thesis overland vehicle communication is referred to as V2X communication.

Figure 2.1 illustrates these V2X communication types.

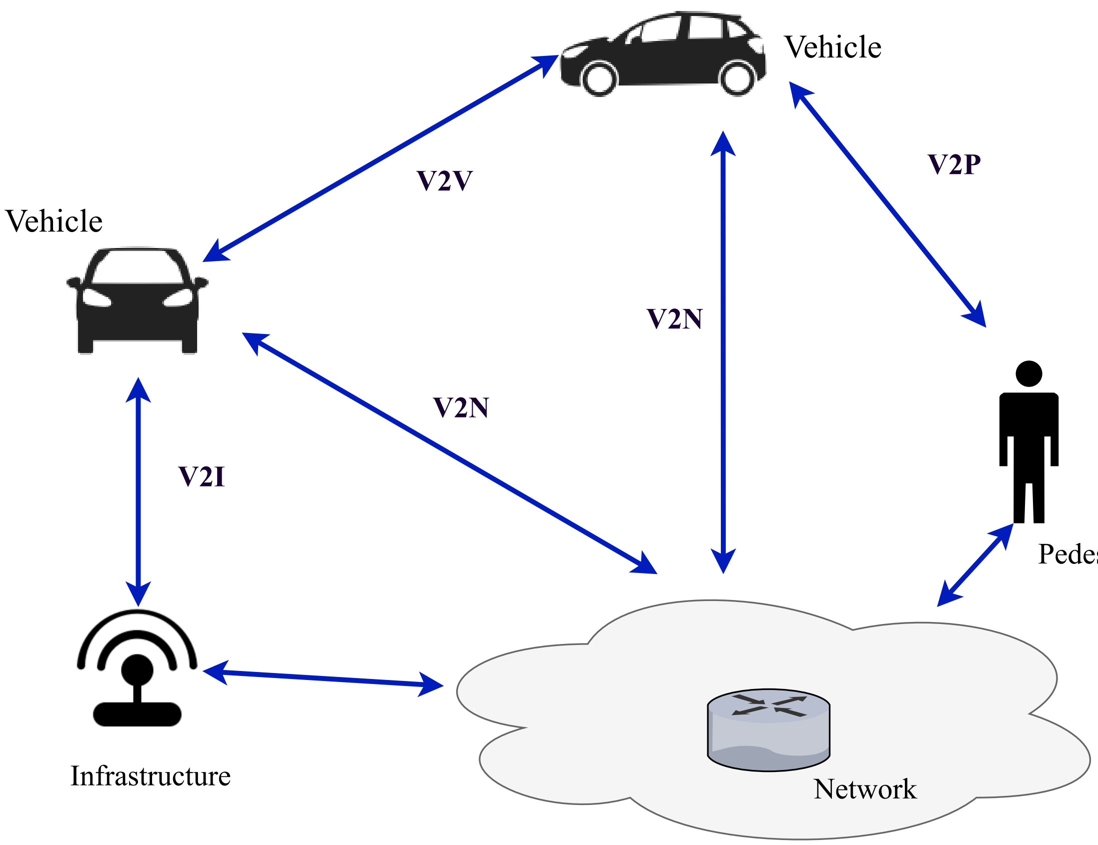

Figure 2.1. V2X communication types.

In [6] V2X communication types are discussed. They are

- V2V communication

Usually V2V applications expect vehicles to transmit messages carrying V2V application information, such as vehicle attributes, traffic dynamics, location, and perception information. Message payloads should be flexible to cater the dynamic amount of V2V application information. If the direct communication range of V2V is limited, the transported information can be forwarded by infrastructure based V2V communications, such as road side units (RSU), application servers, edge cloud servers, and etc.

- V2I communication

Vehicle will be transmitting information with a RSU or a locally relevant application server. Application server can choose the received user equipment (UE) information based on different transmission modes, such as broadcast, unicast, and multicast. A particular application server will serve its all UEs defined geographical area. Multiple number of application servers can be employed to serve overlapped areas.

- V2P communication

Similar to V2V applications instead of a vehicle, in V2P communication information is exchanged between pedestrian UEs and vehicle. V2P services can be used to warn pedestrians using the information from vehicles in the vicinity or a vulnerable road user UE can give a warning to the nearby vehicles. Different from V2V, a pedestrian UE supporting V2P needs to be low power devices. Therefore radio sensitivity will be lower than a vehicle's UE and pedestrian UE supporting V2P applications cannot transmit frequently similar to most IOT devices.

- V2N communication

In V2N communication vehicle will communicate directly with a network node. Directly sharing information with the network for high priority services using evolved packet switching (EPS) is an example for V2N communication.

2.2 V2X Applications and Requirements

V2X applications cover a broader range of requirements for ITS. For convenience these applications are classified as few main categories [5]. They are infotainment, traffic efficiency, traffic safety and autonomous driving, described below.

- Infotainment

Infotainment refers to services required by passengers when they are not driving which are generally entertainment and informative services. Examples are live video transmission, augmented reality (AR) or virtual reality (VR) transmissions, and geo specific advertisements. Infotainment services will have low latency requirements of order 500-1000 ms and higher data rates around 100 Mbps. Coverage availability is a key requirement for this use case. On board caching of library type content is an complementary solution, but it will depend on the evolution of legal frameworks for content right management [7].

- Traffic efficiency

Optimizing the vehicle traffic flow is the main objective of traffic efficiency related services. Common use case is on board GPS system which will automatically calculate the best route for the vehicle from starting point to destination. For general traffic efficiency applications low latency communication, positioning accuracy, and robust network connections are essential. Comparing the technical requirements, they fall between the traffic safety and infotainment [8].

- Traffic safety

Traffic safety services have taken lot of attention over the time due to its ability to reduce traffic accident which will result in reducing the causalities and damages to humans, vehicles, and properties. When it comes to traffic safety related V2X services are characterised by their broadcast frequency, packet error rate and round trip latency. Different regulatory bodies have defined different values for these parameters. For example European telecommunications standards institute (ETSI) has defined round trip delay for pre-crash warnings as 50 ms and US Department of Transportation has defined the minimum round trip delay should be less than 20 ms [8].

- Autonomous driving

Autonomous driving is the most popular V2X use case in the 5G era. Autonomous driving detects the surrounding environment by sensors. Then sensory information is processed to identify appropriate navigation paths as well as obstacles. In general autonomous driving refers to applications needed for enabling fully automated driving such as vehicle platooning and cooperative manoeuvres for collision avoidance or automated overtaking.

Latency requirements for these applications are stringent which makes autonomous driving one of the most challenging use cases under URLLC. Expected low latency is few milliseconds and packet error rates up to 10^{-5} is expected to guarantee the ultra high reliability high positioning accuracy down to few tens of centimeters. Autonomous driving is becoming a reality and it involves key milestones on the way for fully autonomous driving. The society of automotive engineers (SAE) has defined six levels of driving automation ranging from Level 0 - fully manual to Level 5 - fully autonomous [9], described below

1. Level 0 - No Driving Automation: Most of the vehicles belong to Level 0 where vehicle is manually controlled. Human is responsible for driving the vehicle although some systems are there to help to driver. As an example emergency braking system is used to help the driver, but it does not drive the vehicle. Therefore it is not considered as an autonomous driving component.

2. Level 1 - Driver Assistance: Vehicles consisting of advanced driver assistance systems or ADAS are considered to be in Level 2. Human driver can take control of the driving at any time. Vehicle itself can perform steering and controlling the speed. Examples are Tesla Autopilot and Cadillac Super Cruise systems by General Motors.

3. Level 3 - Conditional Driving Automation: In lower levels human driver is expected to observe the environment. However, in level 3 vehicle performs steering, speed

control and monitoring the environment. According to National Highway Traffic Safety Administration (NHTSA) level three and above are considered as automated driving systems (ADS). In terms of capability there is a significant difference between level 2 and 3. In both levels driver is expected to monitor its surrounding, but in level 3 vehicle can handle certain driving conditions by itself. Highway driving is a common application.

4. Level 4 - High Driving Automation: In level 4 vehicle can intervene in case of an emergency. In this level human interaction is minimal, but it is possible for the human driver to override the autonomous driving system. Level 4 vehicles can operate in self-driving mode. They will be subjected to geofencing, i.e, until proper regulations and infrastructure is developed vehicles are allowed to self drive within a limited area only. Waymo LLC is an example project which is testing level four vehicles.

5. Level 5 - Full Driving Automation: In level 5 no human interaction is needed and vehicle will control all the driving tasks. There will be no geofencing for these vehicles, hence they can drive to any location. Level 5 fully autonomous vehicle projects are ongoing around the world but non of them are still open to general public [10].

Technical requirements for V2X applications are summarized in Table 2.1.

Table 2.1. V2X application categories and technical requirements

Application category	**Latency (ms)**	**Throughput (Mbps)**
Infotainment	500-1000	upto 100
Traffic efficiency	100-500	10-50
Traffic safety	20-100	0.5-700
Autonomous driving	1-100	upto 20 000

2.3 V2X Communication Technologies

Concept of V2X communication has been in focus for more than twenty years. The initial deployments of V2X communications were for electronic toll collection and low rate communication between the peer vehicles or RSUs. With the development of these services the standardization body Institute of Electric and Electronics Engineers (IEEE) defined the standard. Due to the focus and development around vehicular communications 3GPP published release 14 of LTE standards for V2X communication. To further develop the release 14 and to match the requirements from the automotive industry release 15 was published and currently work is ongoing for release 16 focusing on the 3GPP NR initiative [5].

At present two key technologies focusing on V2X communication are Dedicated Short Range Communication (DSRC) and Cellular V2X (C-V2X). Since 2004 Federal Communications Commission of United States dedicated to use 75 MHz of bandwidth at

5.9 GHz for DSRC. For its physical and medium access control layer, DSRC depends on the IEEE 802.11p standard. However, DSRC has been challenged by lack of scalability and lack of performance in highly mobile scenarios. Due to its additional link budget, better congestion control, reliability, interference and better non line of sight capabilities C-V2X offers superior performances to DSRC [11] [12].

From existing literature [13] it can be shown that for basic safety applications both DSRC and C-V2X can deliver reliable service levels around 100 milliseconds for lower vehicle densities.

Considering advanced use cases demanded by the automotive industry and 5G use cases both DSRC and C-V2X are not able to deliver the required performance levels. To further develop these technologies 3GPP is working toward the development of New Radio (NR) V2X for its Release 16, on top of 5G NR that was standardized in 3GPP. NR V2X is expected to support advanced V2X applications [5].

2.3.1 Dedicated Short Range Communication

Some DSRC bands are currently deployed in few countries, 902–928 MHz (North America), 5795–5815 MHz (Europe), and 5770–5850 MHz (Japan), while the rest of the DSRC allocated spectrum bands are currently not in use. Depending on the of V2X application and the supporting communication standard each DSRC band is either used as a single frequency channel or divided into multiple channels. Physical and medium access control (MAC) layers of DSRC are based on IEEE 802.11p standard, which is based on wifi standard IEEE 802.11a which has low mobility applications. Therefore changes have been made to the previous wifi standards to characterize the high mobility scenarios occurring in vehicular communications [14].

DSRC uses an orthogonal frequency division multiplexing (OFDM) based physical layer and channel bandwidth is 10 MHz. Compared to Wi-Fi, DSRC sub carrier spacing is reduced by a factor of two. Carrier sense multiple access (CSMA) is the MAC protocol used in DSRC [15]. However, it suffers from a high collision probability under medium or high traffic loads due to its simple random access scheme, which is not suitable for high reliability V2X communication.

DSRC is an ad-hoc communication scheme which does not need network infrastructure. But installation of many new access points (APs) and gateways are required by 802.11p which increases the cost of deployment. Also there is no clear technological evolution path for DSRC as well [16].

2.3.2 Cellular V2X

V2X standard developed by 3GPP in release 14 is referred as cellular V2X, LTE-V and LTE-V2X. It mainly aims to utilize the existing cellular communications infrastructure to support V2X services. Infrastructure elements are not always reliable. Therefore direct communication is needed between V2X elements. 3GPP introduced LTE sidelink for device to device communication in Release 12 focusing on public safety consisting of two modes, mode 1 and mode 2. These modes increased battery life at the cost of increasing the latency. Therefore these modes were not suitable for low latency applications of V2X.

In release 14, 3GPP introduced mode 3 and 4 to support services which needed low latency V2X requirements. In mode 3 radio resources are managed by the cellular network and in mode 4 vehicles manages the radio resources autonomously. Since traffic safety related V2X services cannot rely on the cellular network, mode 4 is considered as the baseline V2V transmission mode [17]. LTE sidelink is defined as a direct communication link between two LTE devices without going through a base station, illustrated in Figure 2.2.

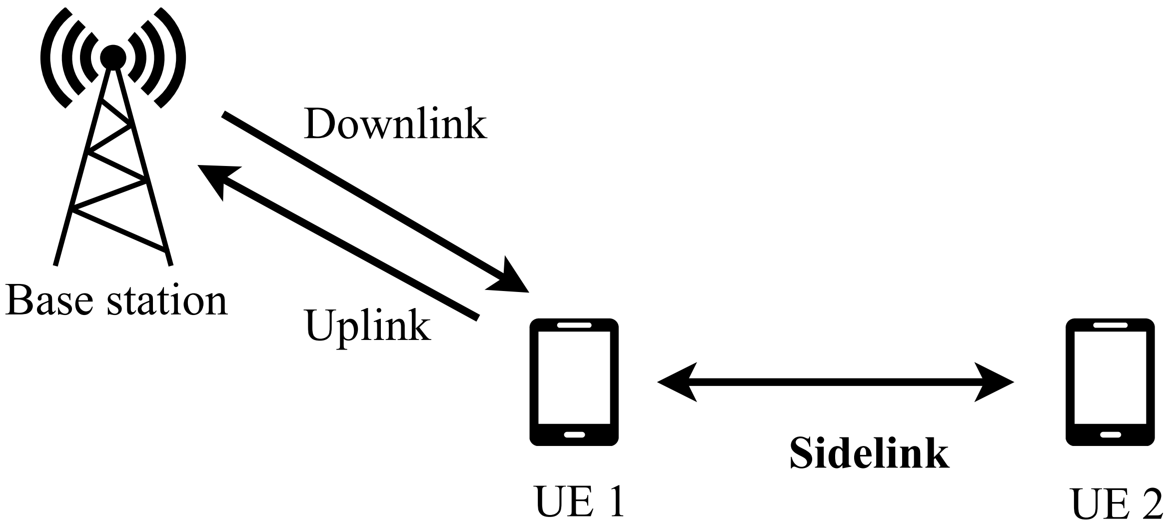

Figure 2.2. Sidelink visualization.

Cellular V2X has two main interfaces, namely Uu interface to enable vehicle-cellular infrastructure communication and PC5 interface to enable vehicle-vehicle (or other elements such as pedestrians). Uu and PC5 interfaces in cellular V2X communication is illustrated in Figure 2.3.

Time-frequency resource structure is similar in C-V2X and LTE. Sub frame is the smallest unit which can be allocated in time 1 millisecond comprising of 14 OFDM symbols and smallest frequency unit is 12 sub-carriers of 15 kHz. Quadrature Phase Shift Keying (QPSK) or 16-Quadrature Amplitude Modulation (QAM) schemes with turbo coding can be used in each OFDM sub carrier [13].

The data is transmitted in transport blocks (TBs) over physical sidelink shared channels (PSSCH). In C-V2X sub channels are defined as a group of resource blocks (RBs) in the same sub frame, and also the number of RBs per subchannel may vary. Sub channels are used to transmit data and control information. In addition to data, sidelink control information (SCI) messages are transmitted over PSCCH.

Full packet to be transmitted is contained in the TB. Associated SCI which is known as a scheduling assignment, should be transmitted by the node which initiates the transmission. Information regarding the modulation schemes, coding schemes, resource blocks used and resource reservation interval for semi persistent scheduling (SPS), which are used to transmit the TB is included in the SCI. In order to decode the received TB, SCI must be received correctly. TB and SCI must be in the same subframe. A TB and its associated SCI must always be transmitted in the same subframe. This is referred to as hybrid automatic repeat request transmission in the 3GPP [18].

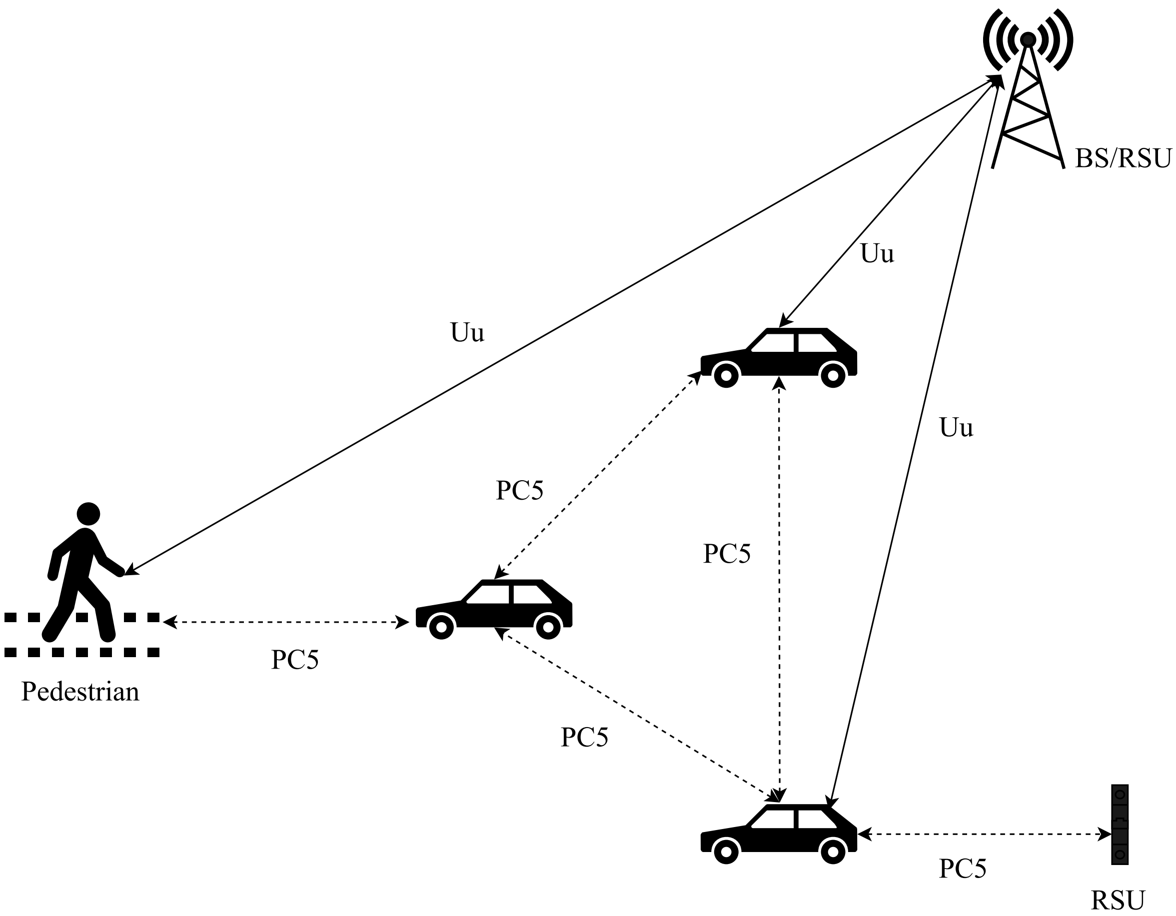

Figure 2.3. Uu and PC5 interfaces in Cellular V2X communication.

There are two sub channelization schemes defined by 3GPP. Adjacent PSCCH and PSSCH is the scenario where SCI and TB is placed in adjacent RBs. SCI is allocated first two RBs of the first subchannel in every transmission. TB is allocated RBs after the SCI allocation and it can occpy several subchannels and due to the size if it needs to be allocated from the following subchannels, that is also allowed. In nonadjacent PSCCH + PSSCH RBs are considered to be in pools. SCIs occupy two RBs and a pool is defined to transmit SCIs only. Another pool is reserved to TBs. The demodulation reference signal (DMRS) is used for channel estimation. In LTE, DMRS symbols are inserted in two of the fourteen OFDM symbols. But in cellular V2X four DMRS symbols are used in one subframe to account for high mobility [19].

2.3.3 New Radio V2X

According to 3GPP it is not intended NR V2X to replace the services offered by LTE V2X. Instead, the NR V2X shall complement LTE V2X for advanced V2X services and support interworking with LTE V2X, since the LTE V2X is already standardized and commercial deployments are happening. At least from 3GPP RANs technology development standpoint, the focus of NR V2X study is to target advanced V2X use cases. However, this does not imply that NR V2X capabilities are necessarily restricted to advanced services [20].

NR V2X is destined as 3GPP V2X phase 3 and would support advanced V2X services beyond services supported in LTE release 15 V2X. The advanced V2X services would require enhanced NR system and new NR sidelink to meet the stringent requirements. NR V2X system is expected have a flexible design in support of services with low latency and high reliability requirements. NR system also expects to have higher system capacity and better coverage. The flexibility of NR sidelink framework would allow easy extension of NR system to support the future development of further advanced V2X services and other services. It is important that NR V2X will be able to provide unified support for all V2X applications including the basic safety applications supported by previous standards for NR V2X to be successful.

Flexible framework of NR allows different services and QoS requirements such as scalable slot duration, mini slot and slot aggregation, self contained slot structure, traffic preemption for URLLC and support for different numerologies for different services [21]. NR framework is flexible as shown in Figure 2.4.

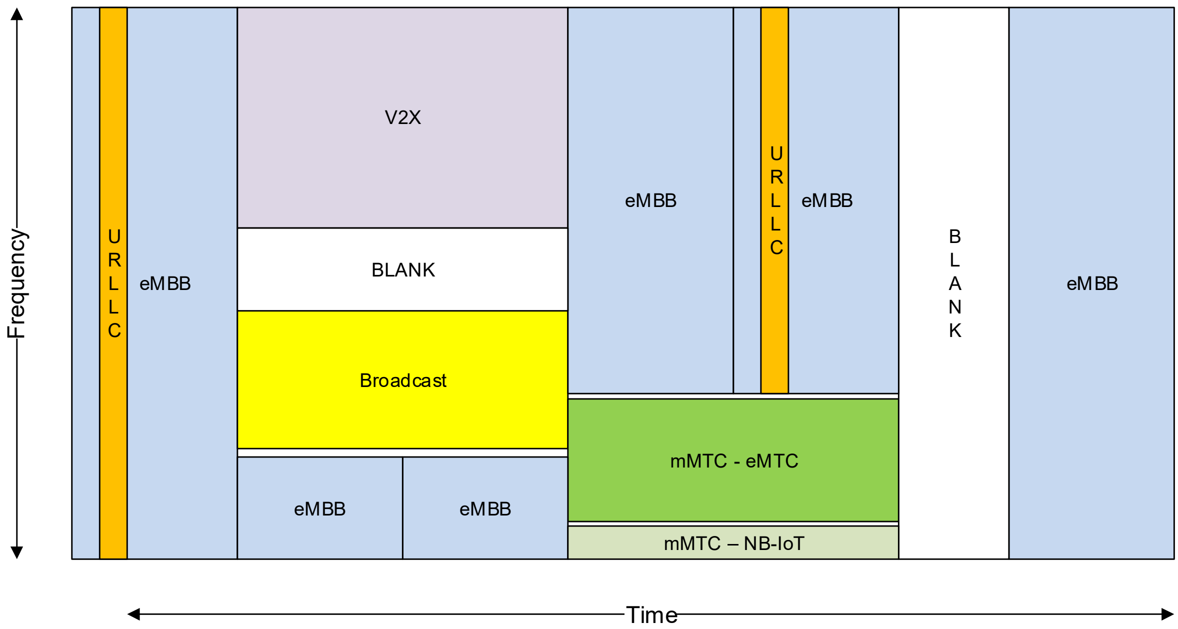

Figure 2.4. Flexible framework for NR [21].

NR V2X services can be categorized to unicast, groupcast and broadcast service types. In unicast communications one UE communicates with only one UE, in groupcast communication transmitting UE communicates with the selected group of UEs only. Broadcast transmission enables the communication of the transmitting UE with all the UEs it establish a communication. In Cellular V2X only broadcast transmissions were allowed, but in NR V2X simultaneously one vehicle will have several operating modes. As an example in vehicle platooning, the leading vehicle (primary vehicle) communicates with the other vehicles using groupcast mode and it uses broadcast mode to transmit periodic messages to other vehicles in the vicinity but not in the platoon as shown in

Figure 2.6. These modes were defined in LTE D2D Identification of the packets as unicast, groupcast and broadcast is a layer 2 function.

When a packet arrives at a transmitting UE, it is assumed that the higher layers notify whether the packet must be sent in unicast, groupcast or broadcast mode. Thus, the physical layer of the UE must always decode the packet and send it to the higher layer. NR V2X will dene these transmission modes at the physical layer.

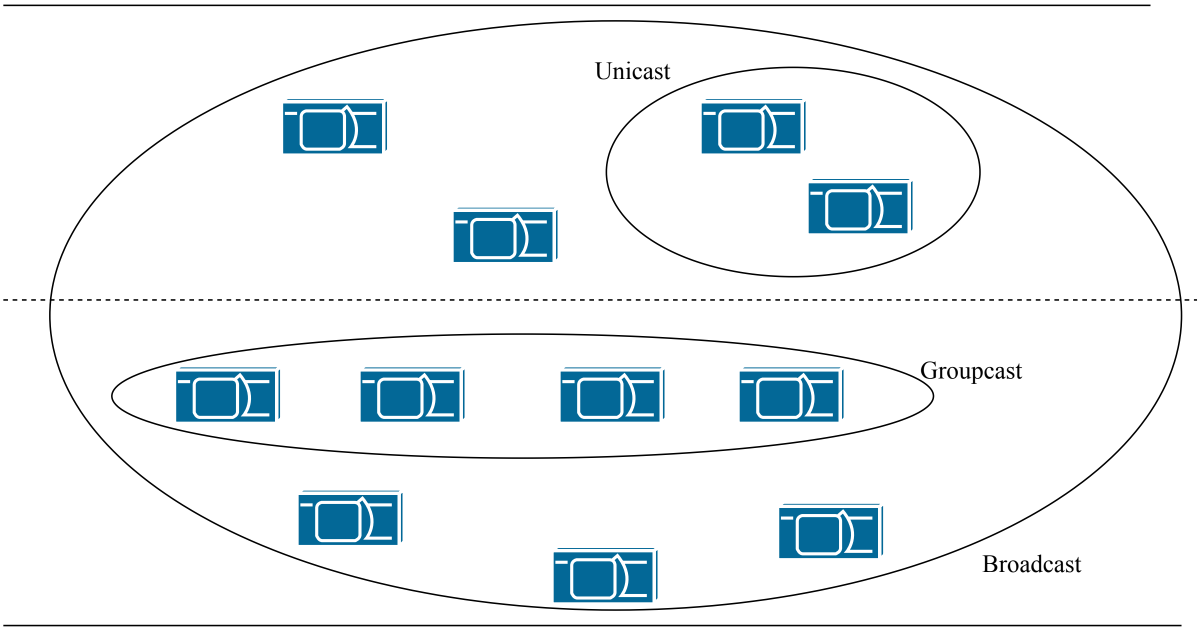

Figure 2.5. Communication types in NR V2X.

For NR 3GPP agreed to use orthogonal frequency division multiplexing (OFDM) with a cyclic-prefix (CP) for uplink and downlink communication after assessing waveform proposals. Using CP-OFDM, multiple-input multiple-output (MIMO) transmissions can be implemented with low complexity and low cost. To improve uplink coverage discrete Fourier transform (DFT) spread OFDM (DFTS-OFDM) is used in NR. Subcarrier spacing used in NR is different to previous LTE standards. In frequency range 1 (FR1) subcarrier spacings are 15, 30, 60 kHz while 60, 120 kHz will be used in frequency range 2 (FR2). According to 3GPP sub 6 GHz is defined as FR1 (450 to 6000 MHz) and mm Wave frequency range is defined as FR2 (24250 to 52600 MHz). Mini slot scheduling is supported in V2X. It is the scheduling mechanism if a UE has a low latency messages to be transmitted, they can start the transmission at any of the 14 OFDM symbols and within the slot any any number of OFDM symbols can be allocated. Therefore by combining more slots V2X services which requires large size packets can be accommodated [22].

2.3.4 Coexistence of C-V2X and NR V2X

Cellular V2X equipped vehicles are going to be in the roads in near future. Since the vehicles are used usually more than 10 years, when the NR V2X is deployed it will have to coexist with cellular V2X. Cellular V2X RAT will have 165 KHz carrier subscpacing and NR V2X RAT will support 30 and 60 kHz sub carrier spacing. Therefore it is expected the vehicles will have two RATs supporting both standards. For a vehicle supporting LTE and NR sidelink, there may be some moment that it needs to transmit or receive signals of LTE and NR sidelink. For example, eNB schedules LTE sidelink transmission while gNB schedules NR sidelink transmission at slot n. Then the vehicle would intend to transmit both LTE and NR sidelink signals as shown in Figure 2.7 shows another example of simultaneous transmission of LTE and NR sidelink signals.

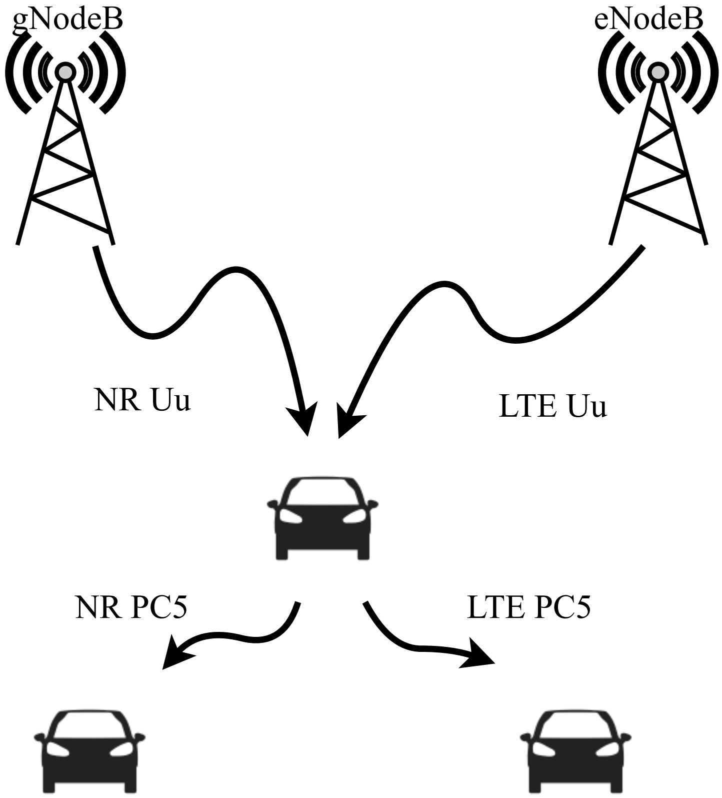

Figure 2.6. V2X coexistence scenarios for NR and LTE Side link.

In these kind of situations, there may be power limitation and processing capability restrictions on the vehicle. Therefore for prioritization power control and dropping rules can be used between LTE and NR sidelink. 3GPP discusses two approaches for the coexistence problem for not co channel scenario, i.e., where cellular V2X and NR V2X are operating in different channels.

Two approaches for V2X coexistence are frequency division multiplexing (FDM) and time division multiplexing (TDM).

1. Frequency division multiplexing: Two radio access technologies (RATs) will operate at the same moment and no tight synchronization is needed. If both RATs operate in the 6 GHz band total radiated power will be restricted by the regulatory limits which will have a impact on delivering required quality of service (QoS) levels by different services. Depending on the service requirements packets can be prioritized and based on that power can be distributed between two RATs. Furthermore the two channels for two RATs should be placed far apart such that it will not affect each other [23].

2. Time Division multiplexing: Transmissions of two RATs will be allocated different time instances. Maximum allowable transmit power can be utilized by both RATs in this approach. Using TDM in coexistence scenarios for services which demands low latency will be challenging. Also tight synchronization requirements are imposed by TDM. Since LTE sidelink uses sensing based resource allocation, in half duplex scenarios if the channels are adjacent for NR and LTE V2X sensing will be impossible during the NR side link transmission [23].

2.4 Millimeter-wave based V2X Communication

The mmWave band refers to frequencies from 30GHz to 300GHz and mmWave band communication has received attention in the recent years in research and development due to the availability of more spectrum in the mmWave bands compared to traditional bands. Hence, mmWave communication is considered to be a potential solution for high bandwidth requirements in 5G era. However, there are many challenges to be overtaken to make it to a reality.

To establish good communication links large number of antennas are required in mmWave communication and transmit and receive beams should be sharper. In mmWave communications, it is essential to have a large number of antennas at the transmitter and the receiver to form sharp transmit and receive beams and establish good communication links. Large number of antennas can be employed in a small factor due to the smaller wavelenghts of mmWave signals.

In Figure 2.7 how mmWave communication can be deployed in V2X scenarios is illustrated. In real life V2X scenarios direct communication with a RSU is not possible in all instances due to blockages and the limitations of transmit power of transmitters. Therefore multiple transceivers are used to overcome these issues. In vehicles multiple mm transceivers can be deployed in different parts of the vehicle eg: in rooftop for V2I communication, in bumpers for V2V communication. Especially for high throughput services such as infotainment in V2X, mmWave communication is a potential solution [24].

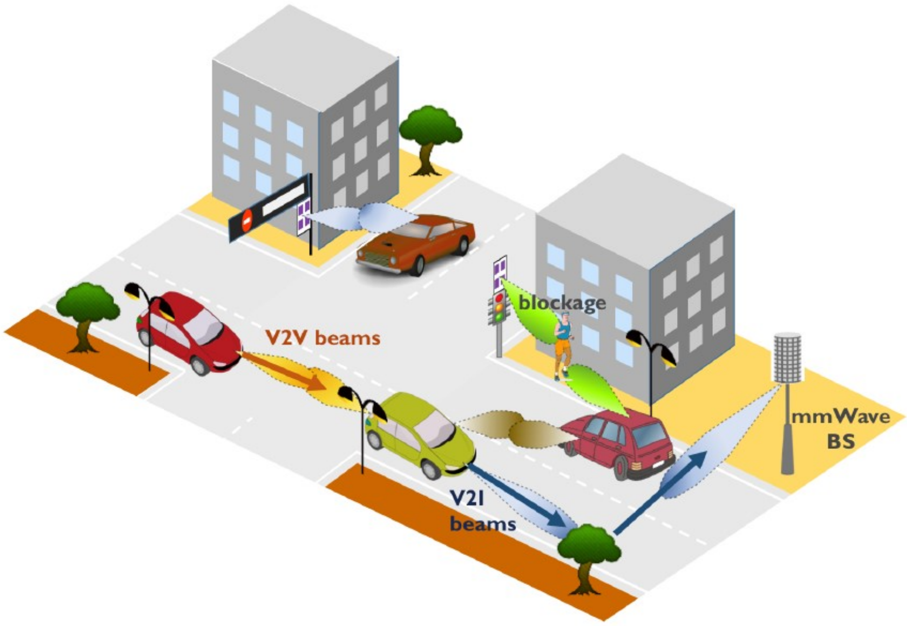

Figure 2.7. mmWave communication used in V2X [24].

However, there are significant challenges in mmWave communication to make it to real world deployments in V2X communication. According to [25] key challenges in V2X mmwave communication are

1. High Path Loss: Free space path loss is proportional to square root of the wavelength. Assuming isotropic propagation millimeter range wavelengths will result in large path loss values. Scattering can occur since the size of raindrops are in the same range of size of wavelength. Furthermore, raindrops are roughly the same size as the radio wavelengths and therefore, cause scattering of the radio signal [26].

2. Low Signal Penetration: mmWave signals do not penetrate most of the solid materials as lower frequency radio signals due to high attenuation. Therefore mmWave signals would not be able to penetrate through solid buildings made of brick or concrete [26].

3. Beam Directionality: Isotropic transmission in the mmWave frequencies will result in a high path loss. As a solution directional communication should be enabled to utilize the beamforming gain. Directional links need precise alignment of transmitting and receiving beams. MmWave links are inherently directional. To generate directional beams, due to the small wavelength, steerable antenna arrays can be implemented. Antenna array can be steered to the required directions by controlling the phase of the transmitted signal, also to achieve a high gain in that

direction, while it provides low gains in other directions. Beam training procedure is used to direct transmitter and receiver beams to point at right directions between them [27].

Beam management consist of four procedures [27]. They are

- Beam sweeping: Using set of transmit and receive beams a spatial area is covered according to predefined directions.
- Beam measurement: Quality of the received signal is evaluated. SINR or other metric can be used to determine the quality of the signal.
- Beam determination: Selecting the best beams from the beam measurement phase.
- Beam reporting: Reporting the quality of the received beams and the decision information to the network.

3 JOINT ADMISSION AND ASSOCIATION FOR VEHICULAR NETWORKS

3.1 System Model

We consider a network with a single base station and a set of vehicles. We denote the set of vehicles as $\mathcal{V}$. The base station or road side unit (RSU) is denoted by b. We define primary vehicles as vehicles which can directly communicate with BS b and vehicles which can directly communicate with primary vehicles, but cannot directly communicate with BS b as secondary vehicles.

We denote the set of all primary vehicles by $\mathcal{P}$ and we label them with the integer $i = 1, ..., I$. The set of all secondary vehicles are denoted by $\mathcal{S}$ and we label them with the integer $j = 1, ..., J$. System model as shown in Figure 3.1 illustrates that primary vehicles act as relays between BS b and secondary vehicles.

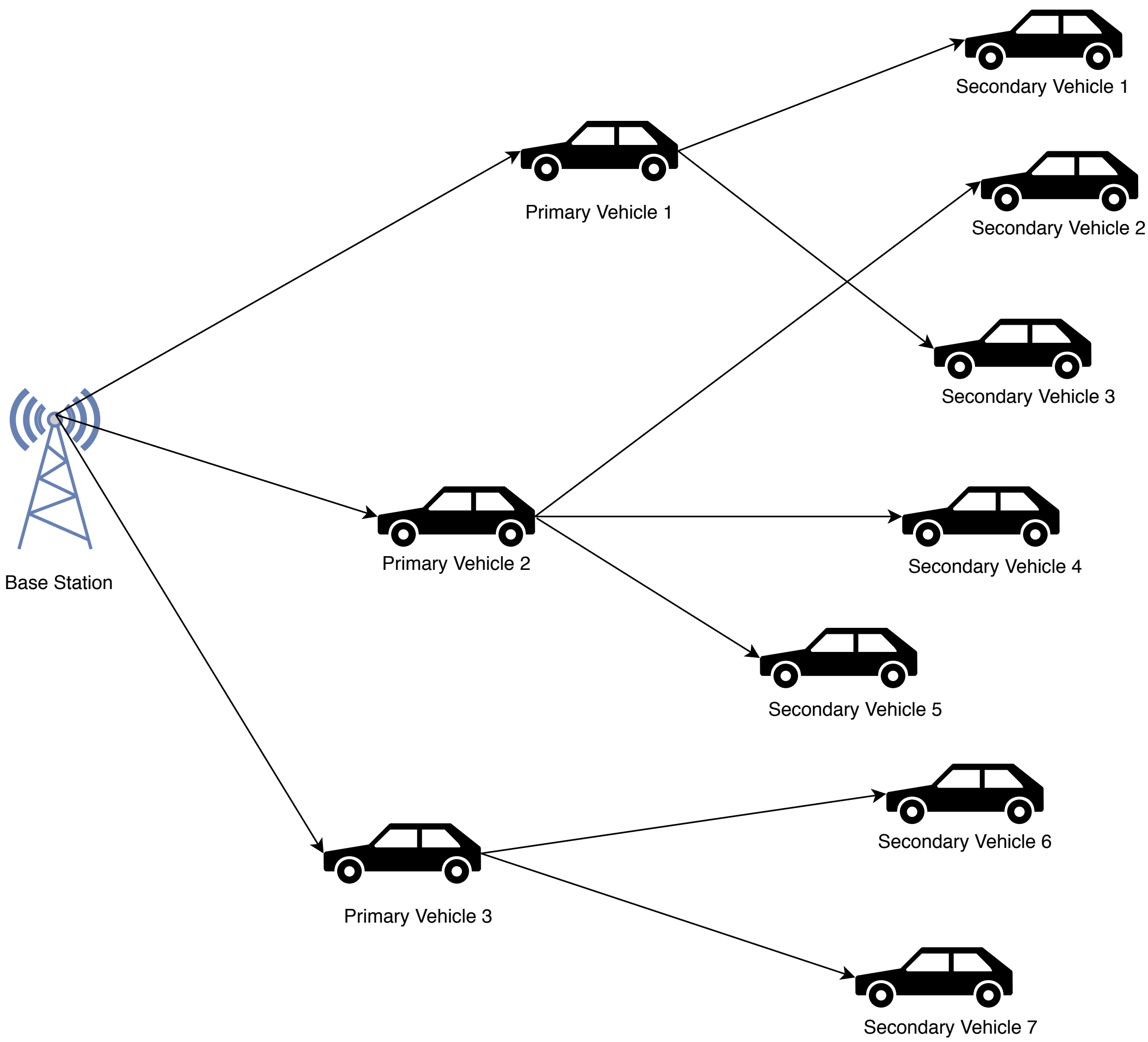

Figure 3.1. System model.

We consider mmWave communication, since it has the ability to deliver higher throughput for V2X use cases [24]. Standard log-distance pathloss model in [28] is adopted to model 60 GHz mmWave channel and to account for blockage effects. In this model the channel gain for link L_{ij} between primary vehicle i and secondary vehicle j is given by

$$g_{ij}^{c} = 10\delta_{ij}\log(d_{ij}) + 15d_{ij}/1000 + \beta_{ij}, \tag{1}$$

where δ_{ij} is the path loss exponent and the second term represents the atmospheric attenuation at 60 GHz. Third term β_{ij} depends on the number of blockers that obstruct the link L_{ij}. Similarly for link L_{ij} between BS b and primary vehicle i we can define g_{bi}^{c}.

Sectored antenna model used in [29] is adopted to approximate the beamforming antenna patterns. In this antenna model, the gain is a constant for all angles in the main lobe and the gain is a smaller constant in the side lobe. According to transmitter gain g_{ij}^{t} and receiver gain g_{ij}^{r} for link L_{ij} are represented by

$$g_{ij}^{t} = \begin{cases} G\left(\varphi_{ij}^{t}\right) = \frac{2\pi - \left(2\pi - \varphi_{ij}^{t}\right)z}{\varphi_{ij}^{t}}, & \text{if } |\theta_{ij}^{t}| \leq \varphi_{ij}^{t}/2 \\ z, & \text{otherwise,} \end{cases} \tag{2}$$

$$g_{ij}^{r} = \begin{cases} G\left(\varphi_{ij}^{r}\right) = \frac{2\pi - \left(2\pi - \varphi_{ij}^{r}\right)z}{\varphi_{ij}^{r}}, & \text{if } |\theta_{ij}^{r}| \leq \varphi_{ij}^{r}/2 \\ z, & \text{otherwise,} \end{cases} \tag{3}$$

where θ_{ij}^{t} and θ_{ij}^{t} represent the alignment errors for transmitter and receiver between primary vehicle i and secondary vehicle j's antenna steering directions and the corresponding boresight directions of primary vehicle i and secondary vehicle j. We represent half power beamwidth of the of link L_{ij} at transmission and reception sides set for the scheduling period by φ_{ij}^{t}. Non negligible sidelobe power by is represented by z, where $0 \leq z \leq 1$. Similar gain equations can be obtained for L_{bi} as well.

According to the studies conducted in [30] for channel measurement and modeling, considering a typical mmWave channel has very few non line of sight (NLOS) components and the channel gains of NLOS paths at mmWave bands are considerably weaker than that of line of sight (LOS) path and NLOS transmissions generally cannot support high throughput services [31]. Therefore, we have only considered the LOS transmission for high throughput scenarios and NLOS transmission is not considered.

For all links from base station to primary vehicles, bandwidth B_{bi} is allocated and for all links from primary to secondary vehicles, bandwidth B_{ij} is allocated. Also, bandwidth allocation for B_{bi} and B_{ij} is assumed to be orthogonal to each other as illustrated in the Figure 3.2. Hence, interference from BS-primary communication to primary-secondary communication and vice versa is considered to be zero. Gaussian background noise power density is denoted by N_0.

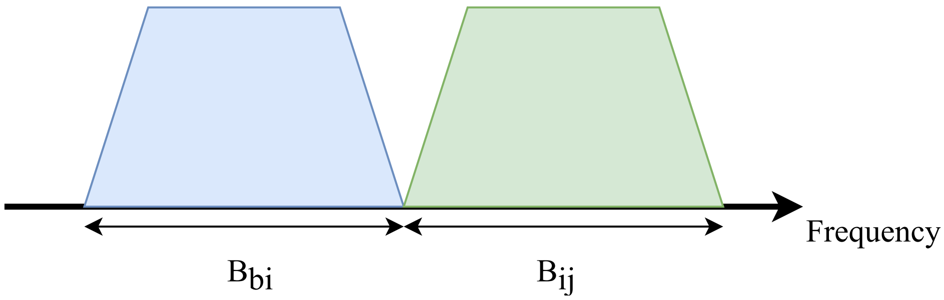

Figure 3.2. Orthogonal bandwidth allocation for B_{ij} and B_{bi}.

The received signal to interference plus noise ratio (SINR) of ith vehicle of BS b is given by

$$\Gamma_{bi} = \frac{P_{bi} g^r_{bi} g^c_{bi} g^t_{bi}}{\sum\limits_{l \in \mathcal{P}, l \neq i} P_{bl} g^r_{bi} g^c_{bi} g^t_{bi} + B_{bi} N_0}. \tag{4}$$

We use X^s matrix to represent the link association in secondary vehicles with primary vehicles. In the matrix X^s i, jth element is represented by

$$x_{ij} = \begin{cases} 1, & \text{if link } L_{ij} \text{ is established} \\ 0, & \text{otherwise,} \end{cases} \tag{5}$$

which indicates whether link L_{ij} is established or not. The received signal to interference plus noise ratio (SINR) of jth secondary vehicle is given by

$$\Gamma_{ij} = \frac{x_{ij} P_{ij} g^r_{ij} g^c_{ij} g^t_{ij}}{\sum\limits_{i \in \mathcal{P}} (1 - x_{ij}) P_{ij} g^r_{ij} g^c_{ij} g^t_{ij} + B_{ij} N_0}. \tag{6}$$

To guarantee the quality of service (QoS) of base station to primary vehicle links,

$$\Gamma_{bi} \geq \Gamma^{th}_{bi},\ i \in \mathcal{P}, \tag{7}$$

SINR inequality should be satisfied.

3.2 Problem Formulation

Our goal is to maximize the number of admitted primary vehicles to the system, while associating all the secondary vehicles to the admitted primary vehicles. We denote the generic set of admitted primary vehicles by $\tilde{\mathcal{P}}$. We now formulate this design problem as a mathematical optimization problem. We introduce the non-negative auxiliary variable a_{bi} for link association between BS and primary vehicles and consider the set of relaxed SINR constraints as

$$\Gamma_{bi} \geq \Gamma^{th}_{bi} - a_{bi}, \forall i \in \mathcal{P}. \tag{8}$$

In (8), when $a_{bi} = 0$ we recover constraint (7), i.e., the SINR constraint of ith primary vehicle is satisfied. Set of relaxed SINR constraints in (8) can be always made feasible by making a_{bi} large enough. The vector $\mathbf{a}$ is obtained by stacking a_{bi}, i.e., $\mathbf{a} = [a_{b1}, a_{b2}, \ldots, a_{bI}]$.

In order to enable communication between primary and secondary vehicles, a set of suitable primary vehicles should be chosen. Therefore selecting the set of suitable primary vehicles is formed as a admission control problem. According to the system model, in scenarios where coverage from the base station is not available we try to associate all secondary vehicles to appropriate primary vehicles.

Minimizing the number of users that require a strictly positive value of a_{bi} in relaxed SINR constraint (8) is equivalent to maximizing the number of admitted primary vehicles. Hence, by using above expressions the problem of joint admission control and association optimization problem can be expressed as

$$
\begin{aligned}
\text{minimize} \quad & \| \mathbf{a} \|_0 \\
\text{subject to} \quad & \Gamma_{bi} \geq \Gamma_{bi}^{th} - a_{bi}, \quad \forall i \in \mathcal{P} && \text{(9a)} \\
& a_{bi} \geq 0, \quad \forall i \in \mathcal{P} && \text{(9b)} \\
& \sum_{i \in \mathcal{P}} P_{bi} \leq P_b^{max}, \quad \forall i \in \mathcal{P} && \text{(9c)} \\
& 0 \leq \sum_{i \in \tilde{\mathcal{P}}} x_{ij} \leq 1, \quad \forall j \in \mathcal{S} && \text{(9d)} \\
& \sum_{j \in \mathcal{S}} x_{ij} P_{ij} \leq P_i^{max}, \quad \forall i \in \tilde{\mathcal{P}} && \text{(9e)} \\
& \Gamma_{ij} \geq \Gamma_{ij}^{th}, \quad \forall j \in \mathcal{S}, && \text{(9f)}
\end{aligned}
$$

where $\mathbf{a}=[a_{b1}, \ldots, a_{bI}]$ and the variables are a_{bi} and x_{ij}.

Constraints (9a) and (9b) ensures auxiliary variable definition is not violated and constraint (9c) is the power constraint for the base station, where the total power distributed between the primary vehicles is bounded by the maximum power BS can transmit. Constraint (9d) is used to ensure that every secondary vehicle is associated with only one admitted primary vehicle. Constraint (9e) is the power constraint for power distribution between each admitted primary vehicle and its associated secondary vehicles, which is bounded by the maximum transmit power of the primary vehicle. Constraint (9f) ensures that every primary to secondary vehicle link SINR level is above its threshold value.

3.3 Algorithm Derivation

In problem (9) objective function is a ℓ_0 function. Problem (9) is a combinatorial problem and it is NP-hard [32]. Thus, the complexity of finding an optimal solution for the problem grows with the problem size. Therefore, in the sequel, we first approximate the problem so that it becomes non-combinatorial, and then we propose a two-stage suboptimal algorithm to problem (9). We adopt the natural approach of relaxing the objective function to l_1 norm. Hence, the approximated problem can be formulated as below.

$$
\begin{aligned}
\text{minimize} \quad & \| \mathbf{a} \|_1 \\
\text{subject to} \quad & \Gamma_{bi} \geq \Gamma_{bi}^{th} - a_{bi}, \quad \forall i \in \mathcal{P} && \text{(10a)} \\
& a_{bi} \geq 0, \quad \forall i \in \mathcal{P} && \text{(10b)} \\
& \textstyle\sum_{i \in \mathcal{P}} P_{bi} \leq P_b^{max}, \quad \forall i \in \mathcal{P} && \text{(10c)} \\
& 0 \leq \textstyle\sum_{i \in \hat{\mathcal{P}}} x_{ij} \leq 1, \quad \forall j \in \mathcal{S} && \text{(10d)} \\
& \textstyle\sum_{j \in \mathcal{S}} x_{ij} P_{ij} \leq P_i^{max}, \quad \forall i \in \mathcal{P} && \text{(10e)} \\
& \Gamma_{ij} \geq \Gamma_{ij}^{th}, \quad \forall j \in \mathcal{S} && \text{(10f)}
\end{aligned}
$$

where $\mathbf{a} = [a_{b1}, \ldots, a_{bI}]$ and the variables are a_{bi} and x_{ij} for $i \in \mathcal{P}$, $j \in \mathcal{S}$. Note that problem (10) is still not convex in variables.

The proposed two stage algorithm is illustrated in Figure 3.3. First we solve the stage one of the problem by solving

$$
\begin{aligned}
\text{minimize} \quad & \| \mathbf{a} \|_1 \\
\text{subject to} \quad & \Gamma_{bi} \geq \Gamma_{bi}^{th} - a_{bi}, \quad \forall i \in \mathcal{P} && \text{(11a)} \\
& a_{bi} \geq 0, \quad \forall i \in \mathcal{P} && \text{(11b)} \\
& \textstyle\sum_{i \in \mathcal{P}} P_{bi} \leq P_b^{max}, \quad \forall i \in \mathcal{P}, && \text{(11c)}
\end{aligned}
$$

where $\mathbf{a}=[a_{b1}, \ldots, a_{bI}]$ and the variable is a_{bi} for $i \in \mathcal{P}$.

When we obtain the optimal solution of the optimization problem (11), objective function of the problem (10) becomes a known vector and constraints (10a), (10b) and (10c) are satisfied. Hence, we can simplify problem (10) to the following feasibility problem

$$
\begin{aligned}
\text{minimize} \quad & 0 \\
\text{subject to} \quad & 0 \leq \textstyle\sum_{i \in \hat{\mathcal{P}}} x_{ij} \leq 1, \quad \forall j \in \mathcal{S} && \text{(12a)} \\
& \textstyle\sum_{j \in \mathcal{S}} x_{ij} P_{ij} \leq P_i^{max}, \quad \forall i \in \tilde{\mathcal{P}} && \text{(12b)} \\
& \Gamma_{ij} \geq \Gamma_{ij}^{th}, \quad \forall j \in \mathcal{S}, && \text{(12c)}
\end{aligned}
$$

where the variable is x_{ij} for $i \in \mathcal{P}$, $j \in \mathcal{S}$. In the proposed algorithm we solve problem (12) as stage two. We define

$$
e_{bi} = \begin{cases} 1, & \text{if } a_{bi} = 0 \\ 0, & \text{otherwise.} \end{cases} \tag{13}
$$

Admission control vector for the primary vehicles is defined by the optimal solution of the optimization problem (11). We define admission control vector $\mathbf{e}^{\star}$ by stacking e_{bi} to a vector, where $\mathbf{e}^{\star}=[e_{b1}, \ldots, e_{bI}]$ and each element represents whether the corresponding primary vehicle is admitted or not.

Finally, we summarize the proposed algorithm by *Algorithm 1* given below.

Algorithm 1 Algorithm for solving Joint Admission control and Association problem

1: For all vehicles set power thresholds P_b^{max}, P_i^{max}, SINR thresholds Γ_{bi}^{th}, Γ_{ij}^{th} and obtain transmit powers P_{bi}, P_{ij}
2: Solve (11) and find $\mathbf{e}^{\star}$
3: Use $\mathbf{e}$ and solve (12) and find X^s

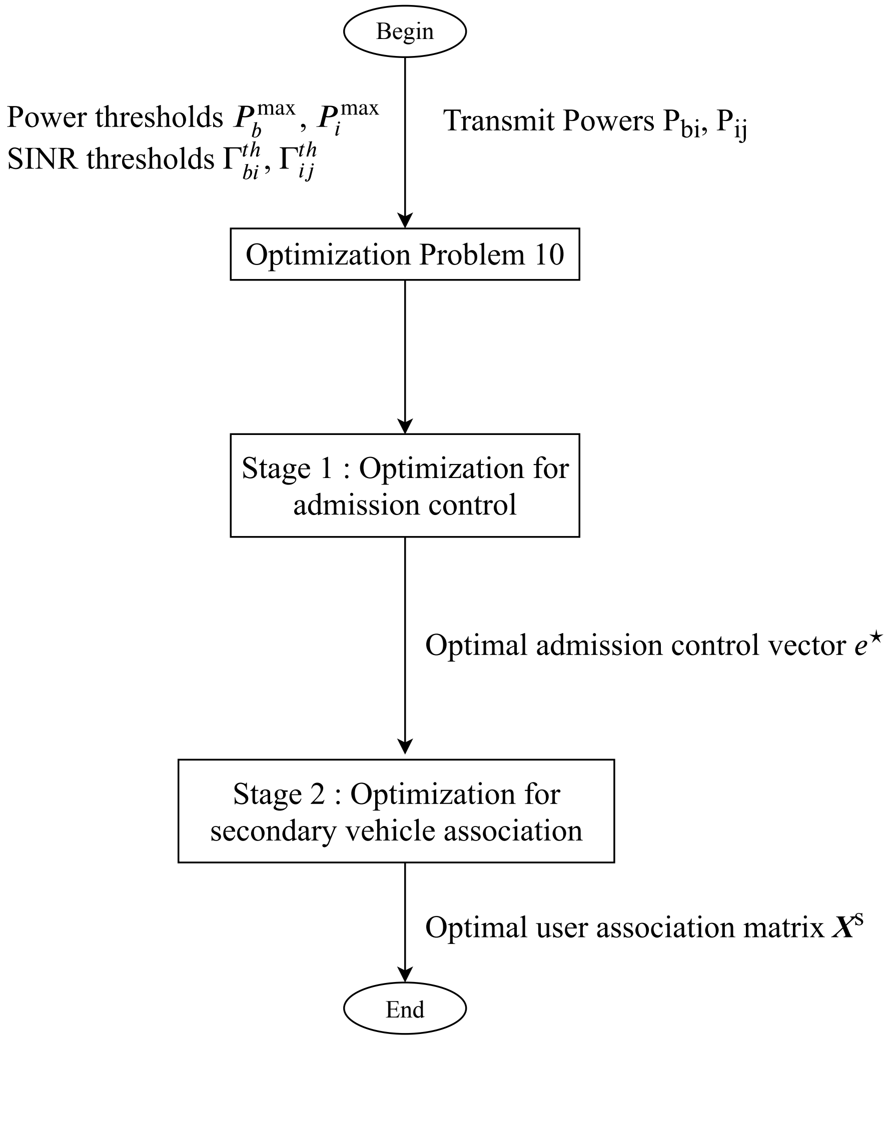

Figure 3.3. Proposed two stage algorithm.

4 SIMULATION RESULTS AND DISCUSSION

4.1 Simulation Parameters

To evaluate the performance of the proposed algorithm simulations have been performed. It is assumed in all links once the alignment procedure has been completed, transmitter and receiver operate in their main lobe, therefore the alignment error between transmitter and receiver for all links from base station to primary vehicle and primary vehicles to secondary vehicles is considered to be zero ($\theta^t_{ij} = \theta^r_{ij} = \theta^t_{bj} = \theta^r_{bi} = 0$).

We have used Matlab for all simulations [33]. To solve admission control algorithm we used CVX, a package for specifying and solving convex programs [34]. Key parameters used for the simulations are given in Table 4.1.

Table 4.1. Simulation parameters

Parameter	**Value**
Half power beamwidth φ	$\pi/6$
Side lobe gain z	0.1
Path loss exponent δ_{bi} and δ_{ij}	2.1
β_{bi} and β_{ij}	75.1
Maximum transmit power of base station P_b^{max}	40 dBm
Maximum transmit power of primary vehicle P_i^{max}	15 dBm
Thermal noise density N_0	-174 dBm/Hz
Carrier frequency	60 GHz

Distance between two nodes i and j are defined by d_{ij}, maximum transmitting distance of b is denoted by d_b^{max} and maximum transmitting distance of a primary vehicle is denoted by d_i^{max}. Hence, we define primary vehicles by

$$\mathcal{P}=\{i|d_{bi}\leq d_b^{max}\ ,\ i\in\mathcal{V}\}, \tag{14}$$

and secondary vehicles are defined by

$$\mathcal{S}=\{j|d_{ij}\leq d_i^{max}\ ,\ j\in\mathcal{V}\}. \tag{15}$$

In our simulations we initialize all the vehicle positions randomly and we refer to arbitrarily generated set of topologies denoted by

$$\mathcal{T}_k=\{d_{bi},d_{ij}|\forall i\in\mathcal{P},\ \forall j\in\mathcal{S}\}, \tag{16}$$

as a single topology realization.

4.2 Simulation Results and Discussion for Stage One

As shown in Figure 4.1 for ten topology realizations we evaluate the number of admitted users from the stage one of the algorithm, keeping a fixed SINR target value. We use ten primary vehicles for the simulations.

As the base line algorithm for comparing the proposed algorithm, exhaustive search has been used, since it can find the optimum solution for the problem. Exhaustive algorithm search for the maximum number of primary vehicles that can be admitted by checking all possible combinations with the given constraints. Topologies are selected according to the set defined in (16).

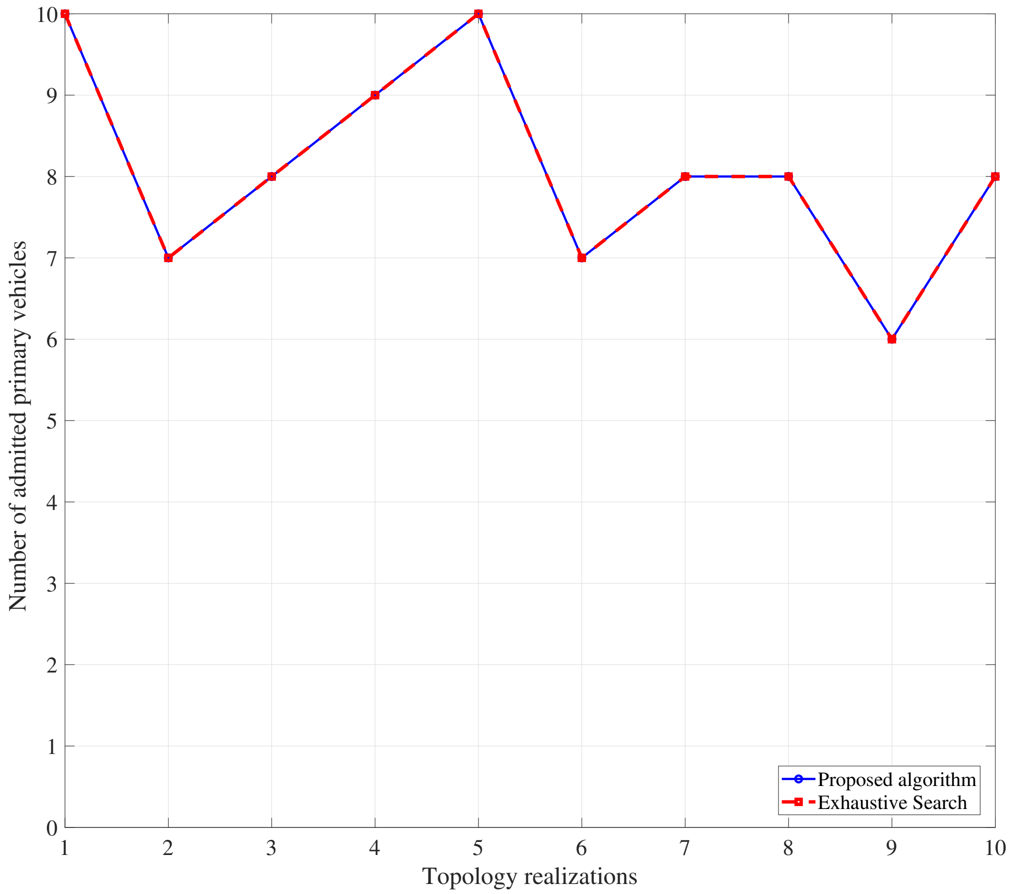

Figure 4.1. Number of admitted vehicles vs topology realizations

Results in Figure 4.1 show that for the considered ten topology realizations the number of admitted vehicles by both algorithms reach the same value. Hence we can observe the proposed algorithm is able to find the maximum number of admitted primary vehicles.

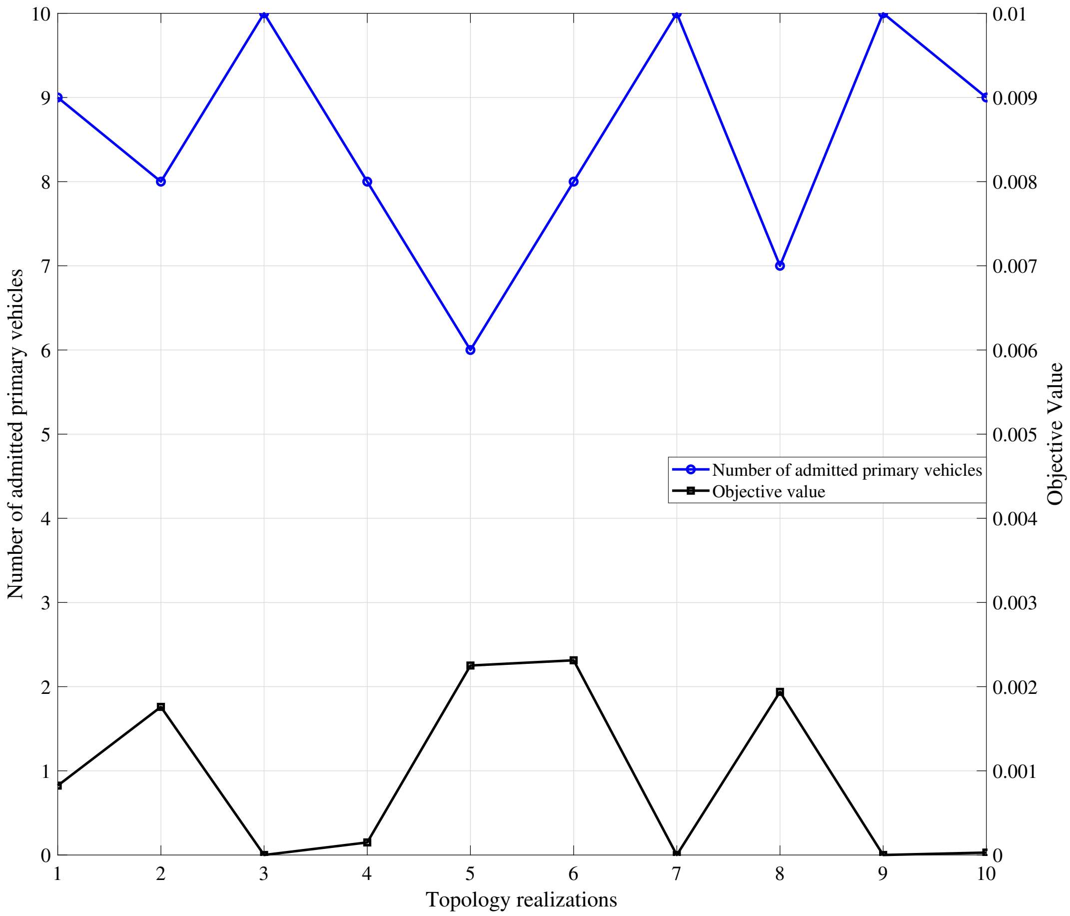

Figure 4.2. Number of admitted primary vehicles and Objective value vs topology realizations

We evaluate the variation of number of admitted users and the objective value of the proposed algorithm is shown in Figure 4.2 for ten topology realizations. We observe that when the objective value reaches the minimum value zero, maximum number of admitted primary vehicles, i.e., number ten is reached.

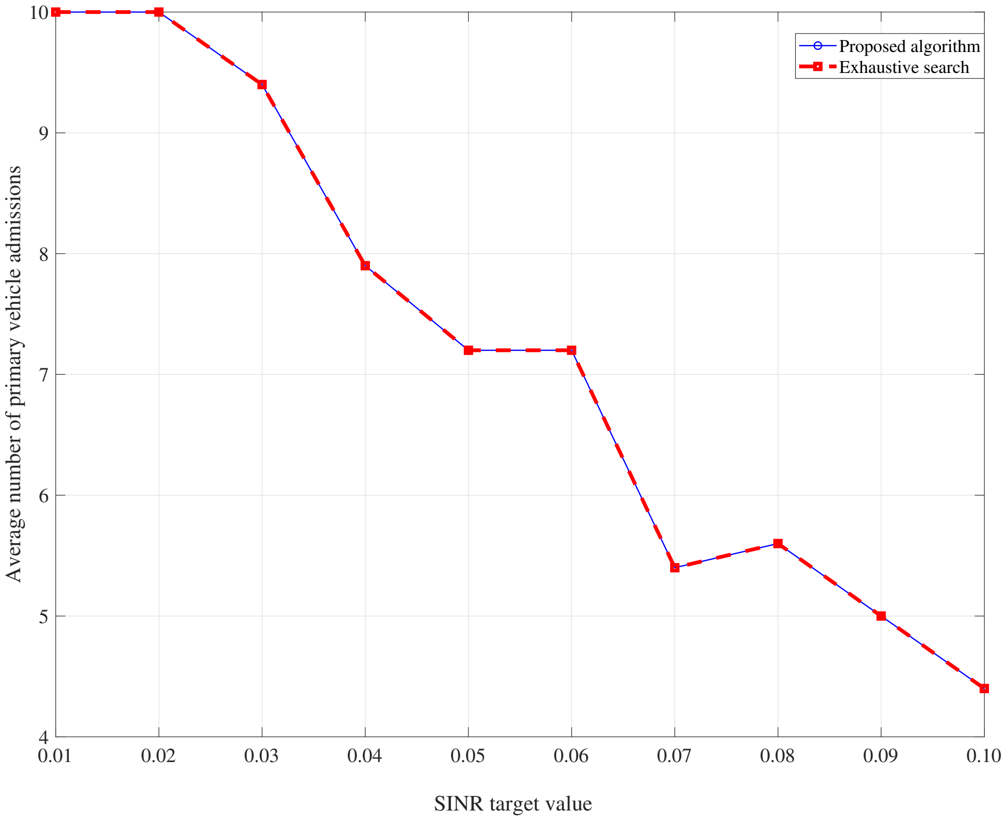

Figure 4.3. Average number of admitted vehicles vs SINR target

We can observe the average number of admitted vehicles is same for both algorithms by referring to Figure 4.3. When the SINR threshold is increased the number of vehicles which can satisfy the requirement decreases. Also this graph confirms that with the varying SINR target value, our proposed algorithm shows a similar performance as in the exhaustive search algorithm (optimal solution) in terms of the objective value.

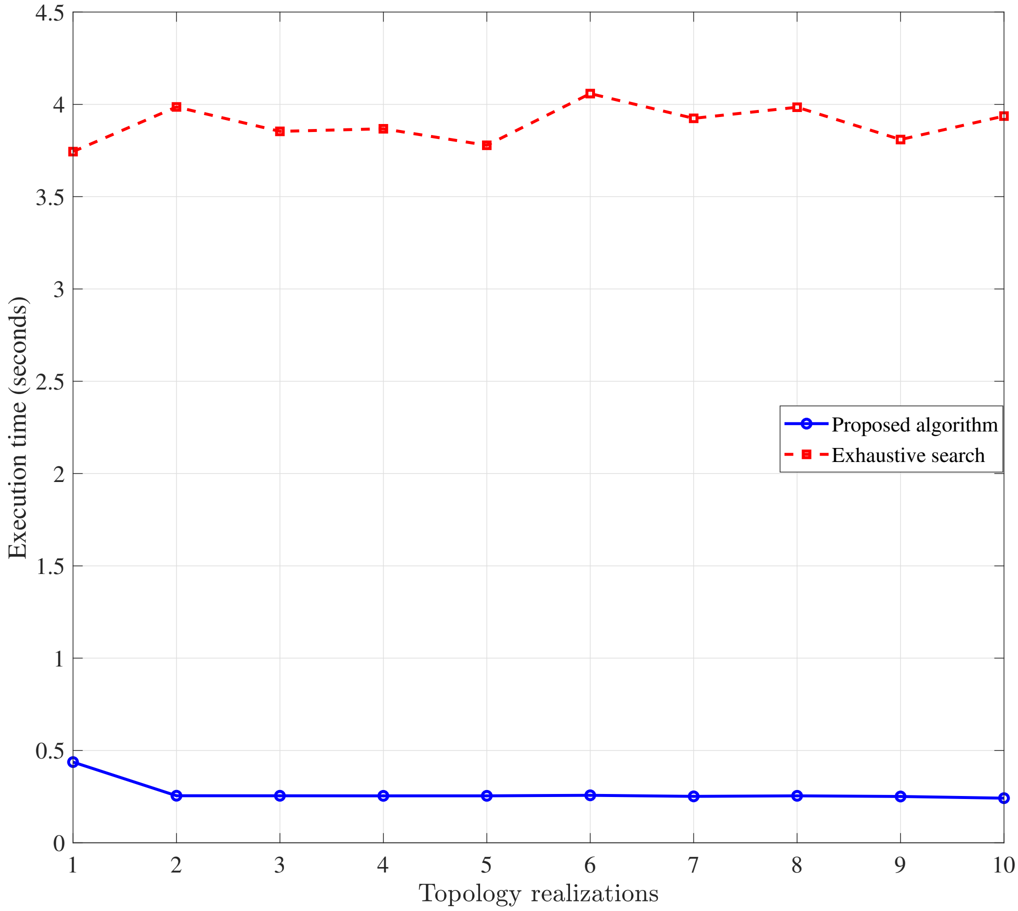

Figure 4.4. Execution time comparison

Next we evaluate the efficiency of the proposed algorithm by comparing the execution time of the proposed algorithm and the exhaustive search for ten topology realizations for a fixed SINR target value in a system consisting of 10 primary vehicles. As seen from Figure 4.4 proposed algorithm performs faster than the exhaustive search algorithm.

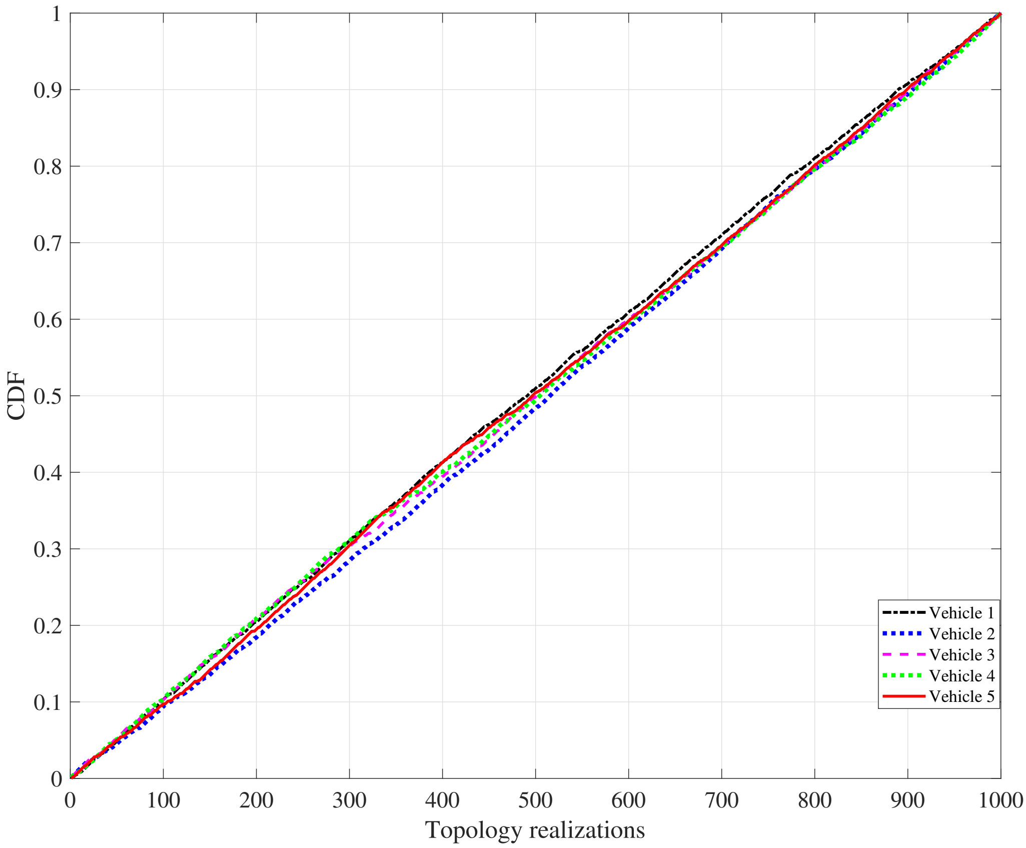

Figure 4.5. CDF of Number of admissions

In order to provide a statistical description of number of admissions of the proposed algorithm, we consider empirically the cumulative distribution function (CDF) plots. We have simulated over 1000 topology realizations in this case. CDF of five primary vehicles which is shown in Figure 4.5.

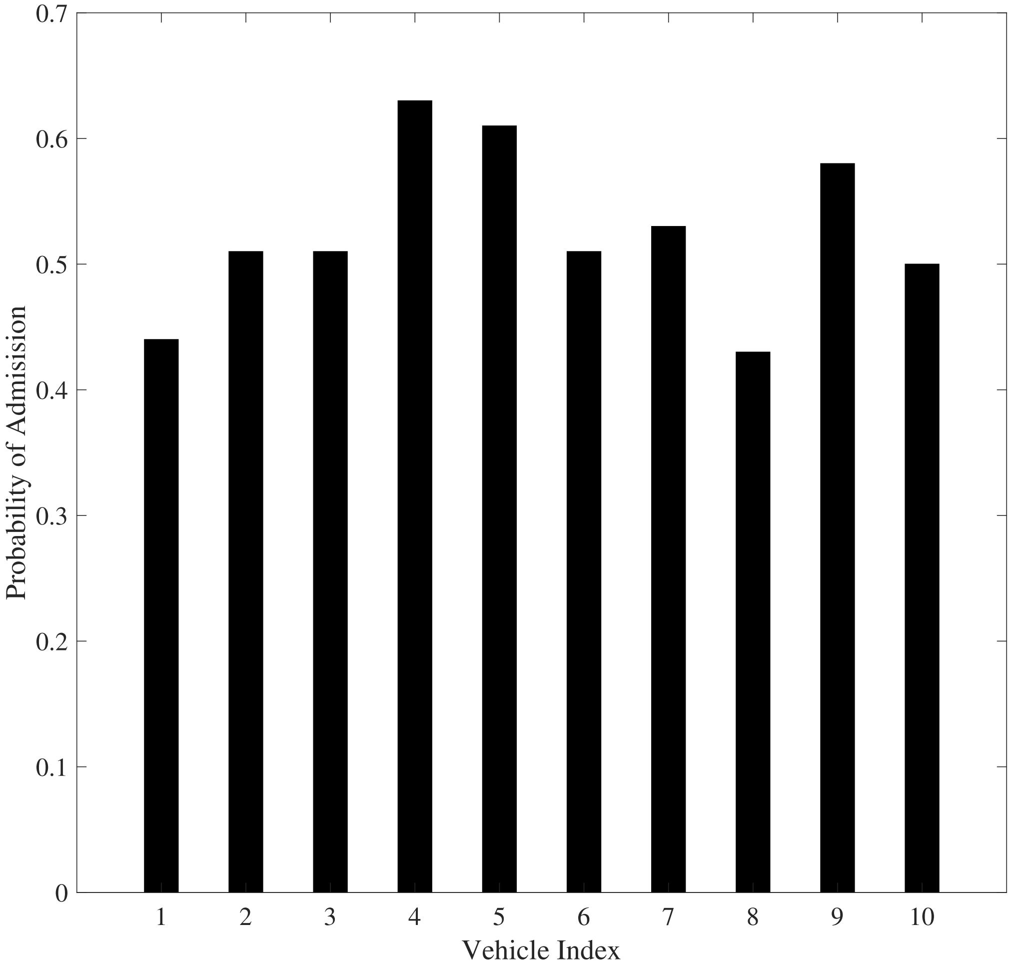

Figure 4.6. Probability of admission vs vehicle index.

Next, for 1000 topology realizations we evaluate the probability of admission for each primary vehicle for a system of ten primary vehicles, for a fixed SINR value. We observe from Figure 4.6 every vehicle is admitted with probability of range 0.4 to 0.7.

4.3 Simulation Results and Discussion for Stage Two

For numerical simulations we consider a system with ten secondary vehicles. We evaluate number of secondary vehicle associations with the target number of secondary vehicle associations. According to the defined system model all secondary vehicles should be associated when the power and SINR constraints are satisfied.

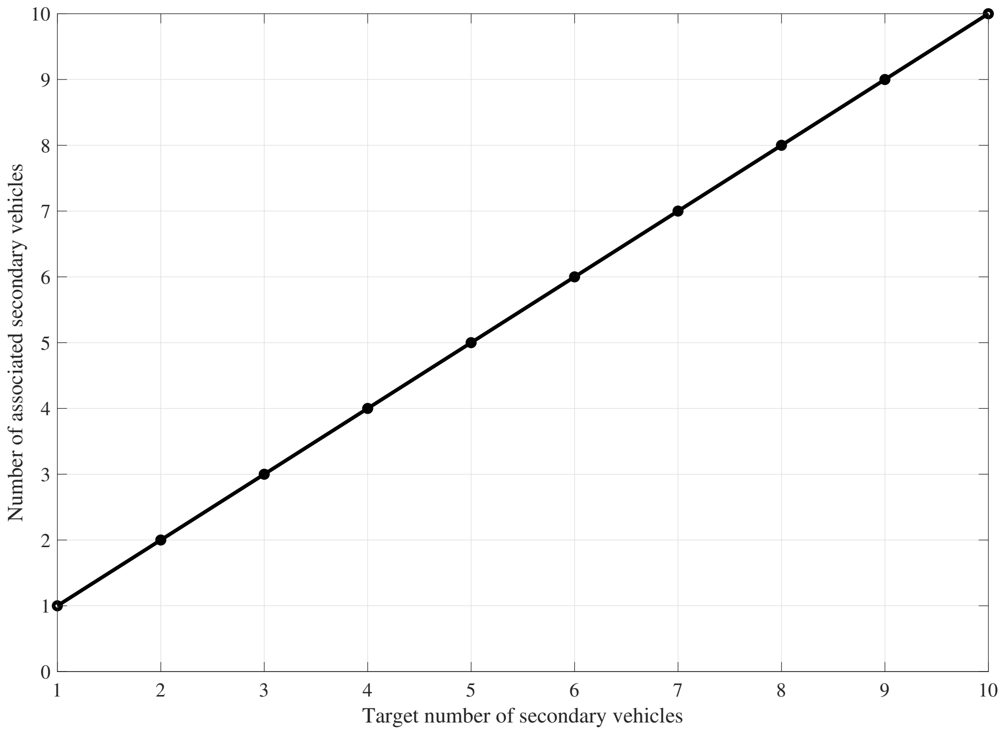

Figure 4.7. Number of associated secondary vehicles vs Target number of secondary vehicles.

From Figure 4.7 it can be observed that number of secondary vehicle associations are equal to target number of associations. Therefore it can be concluded that stage two of the proposed algorithm gives expected performance.

4.4 Overall Simulation Results and Discussion

We evaluate a system with five primary vehicles and ten secondary vehicles for a single topology realization and outputs from the stage one and two of the proposed algorithm, i.e, optimal admission vector $\mathbf{e}^{\star}$ and association matrix X^s are obtained. We denote the resulting system topology realization in Figure 4.8.

Optimal admission vector from stage one is $\mathbf{e}^{\star}= [1\ 0\ 0\ 1\ 1]$. Hence, only primary vehicles 1, 4, 5 have been admitted with the BS. Secondary vehicles 1 to 10 have been associated with the admitted primary vehicles. Therefore we observe that the topology has preserved the defined system model.

From stage one and stage two numerical simulations we can conclude that although the proposed algorithm is a sub-optimal algorithm, it gives optimal performance with improved efficiency.

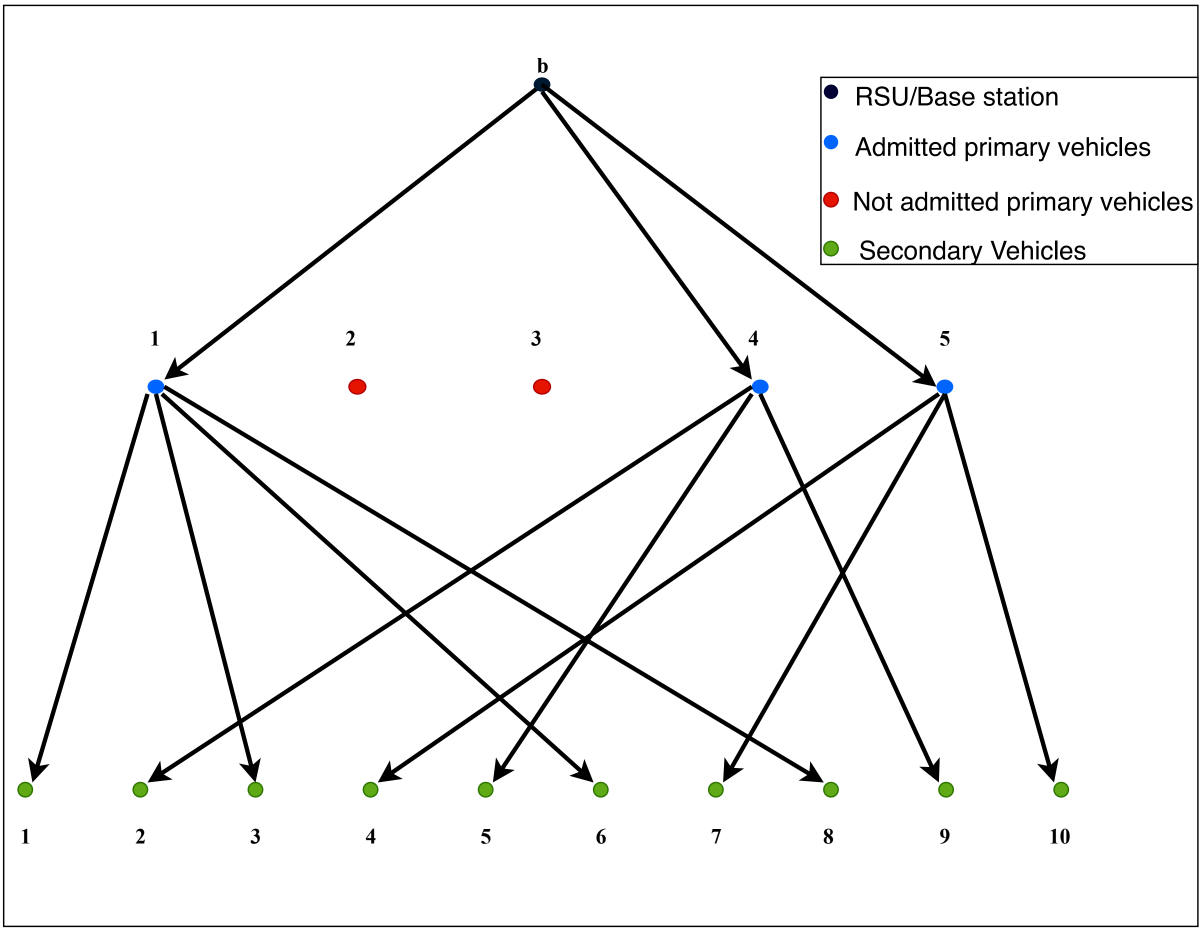

Figure 4.8. Topology realization and connectivity diagram.

5 CONCLUSION AND FUTURE WORK

In this study we have considered vehicles which can communicate with a base station are primary vehicles. They act as relays to secondary vehicles which are out of coverage from the network. An algorithm is proposed employing vehicle to infrastructure and vehicle to vehicle communication to provide coverage for out of coverage vehicles. Hence, the joint problem of admission and association in a single cell downlink vehicular network is studied. The objective is to maximize the number of admitted primary vehicles, while associating all secondary vehicles. We consider the underlying communication system is based on millimeter wave communication at 60 GHz and we cast the optimization problem as an ℓ_0 minimization problem. This problem is known to be combinatorial and NP-hard. Hence, we propose a sub optimal, two stage algorithm to solve it.

We have compared the performance of the proposed algorithm against the exhaustive search algorithm. From simulation results it can be observed, although the proposed algorithm is a sub optimal algorithm it gives optimal performance with improved efficiency. Hence the proposed algorithm is able to determine the optimal association for vehicles which are out of coverage and the optimal admission for vehicles which are in coverage.

In this study transmitting power is equally allocated among the users. Hence, power control can be considered in future research. Also in the current system model we allow a primary vehicle to have many secondary connections. However, this will introduce more signalling from BS to lot of primary users. Instead, by limiting the number of primary vehicles, its effect on the proposed algorithm can be further studied. Currently, fixed and orthogonal bandwidth allocation is considered for primary and secondary vehicles. For future work bandwidth can be considered as a variable and based on non orthogonal bandwidth allocation.

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